Key for Coulomb's Law/Ionization Energy Worksheet

Coulomb's Law

Coulomb's Law states that the force between two particles is directly proportional to the product of their individual charges, Q, and inversely propotional to the square of the distance, d, that separates them

$$F \propto \frac{Q_1 \times Q_2}{d^2}$$

The product of force and distance gives potential energy, E; thus

$$E \propto \frac{Q_1 \times Q_2}{d}$$

How does the potential energy change if we increase the distance between two charges?

- The potential energy becomes smaller because there is an inverse relationship between E and d.

What is the potential energy if the charges are infinitely far apart?

- If d is infinitly large, then the demoninator is infinitly large and the potential energy approaches zero. The potential energy of a "free" electron—one removed from the atom—is zero. This is an important point.

Assuming that d has a finite value and that the potential energy, E, is negative; what must be true of Q_1 and Q_2?

- The only way that the energy, E, can be negative is if the two charges have different signs, which means one must be positive and one must be negative.

If Q for an electron is -1, what is the value of Q for a proton? What is Q for the nucleus of a nitrogen atom of nitrogen?

- The proton must have $Q = +1$. Nitrogen has an atomic number of 7; thus, it has seven protons and a charge of $Q = +7$.

An atom of ^{1}H has a single proton and a single electron separated by a distance d. Is the electron's potential energy positive or negative? If the electron moves further from the nucleus, what happens to its potential energy? Can you extend this conclusion to other atoms?

- The potential energy, E, is negative because $Q_{\text{nucleus}} \times Q_{\text{electron}} = +1 \times -1 = -1$. Increasing the distance, d makes the energy smaller, approaching a limit of zero when the electron and nucleus are infinitly far appart. This should apply to all atoms.

Ioniziation Energy

An electron's ionization energy, IE, is the energy needed to remove an electron from it shell, or $IE = E_\infty - E_n$, where E_∞ is the electron's energy when it is free of the atom and E_n is the electron's energy in its shell. Do you expect ionization energies to have positive values or negative values? Why?

- The ionization energy is positive because $E_\infty = 0$ and E_n is negative.

Suppose an electron has a potential energy of $E = -1.0 \times 10^{-18}$ J in a particular shell. What is the electron's ionization energy?

- The ioniztion energy is $IE = E_\infty - E_n = 0 - (-1.0 \times 10^{-18}\ \mathrm{J}) = +1.0 \times 10^{-18}$ J

Is the ionization energy for an electron 500 picometers (1 pm $= 1 \times 10^{-12}$ m) away from its nucleus larger, smaller or identical in magnitude to the IE for an electron 1000 pm away from the same nucleus? If the ionization energies are not identical, which electron has the greater ionization energy and how many times greater is the ionization energy?

- Because an electron's potential energy is inversely proportional to distance, the closer an electron is to the nucleus, the more negative its potential energy; thus, an electron 500 pm from the nucleus has an ionization energy that is two times greater than that for an electron that is 1000 pm from the nucleus.

Assuming the distance between the electron and the nucleus is the same for a hydrogen atom, H, and a helium ion, He^+, which has the larger ionization energy? Or, are their ionization energies equal?

- The helium ion has the larger ionization energy because its nuclear charge of +2 is twice that for the hydrogen atom.

Suppose you have an atom with two electrons, each at a different distance from the nucleus. Do these electrons have the same ionization energies? If no, which electron has the smaller ionization energy?

- They will have different ionization energies because an electron's potential energy is inversely proportional to its distance from the nucleus. The electron with the smaller ionization energy, therefore, is the one that is further from the nucleus.

Suppose several electrons in an atom are equidistant from the nucleus. Do you expect these electrons to have identical or different ionization energies? Suppose two electrons have identical ionization energies. Will removing one of the electrons affect the other electron's ionization energy?

- All electrons at the same distance from a common nucleus have the same potential energy and the same ionization energy. As there is no reason to expect that removing one electron changes either the charge on the nucleus or the distance between the second electron and the nucleus, there is no reason to expect that removing one electron will affect the ionization energy of the remaining electron. We will see, later, that removing an electron does change the ionization energies of other electrons, which means that our model needs additional work.